Wind Turbines Wakes' Graphics Euromech Colloquium 508, Madrid 2009

p.11, 12 Fast linearized models for wind turbine wakes

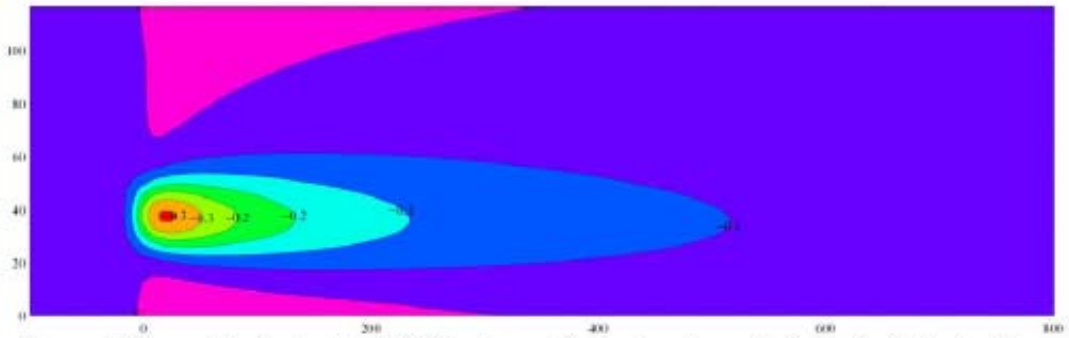
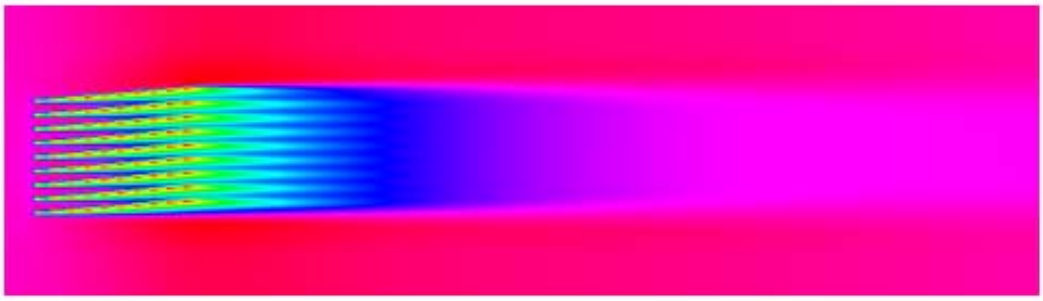


Figure 1. Normalised velocity deficit in the vertical plane through the hub obtained with a linearized model. Wind from left to right.



0 km 10 km

Figure 4. The wake from a hypothetical wind farm with 90 turbines.Wind is from left to right.

p.17 Energy preservation in… wind turbine wakes

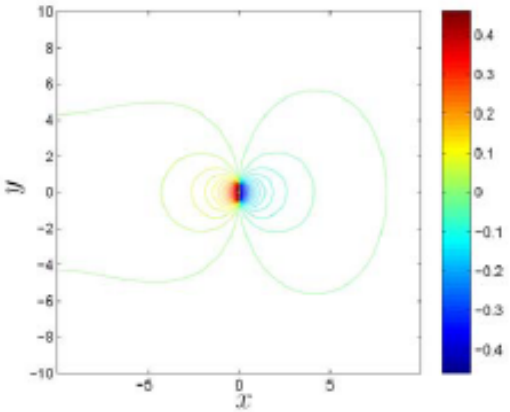


Figure 1: Pressure contours

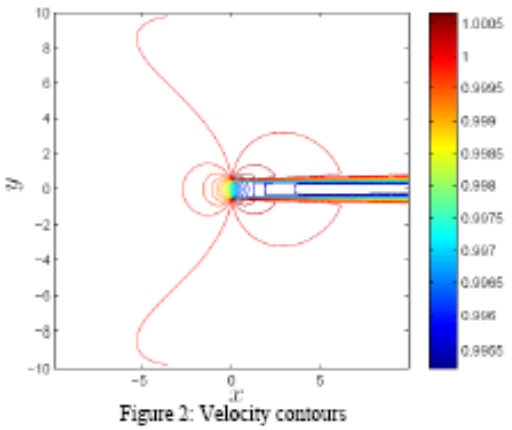


Figure 2: Velocity contours

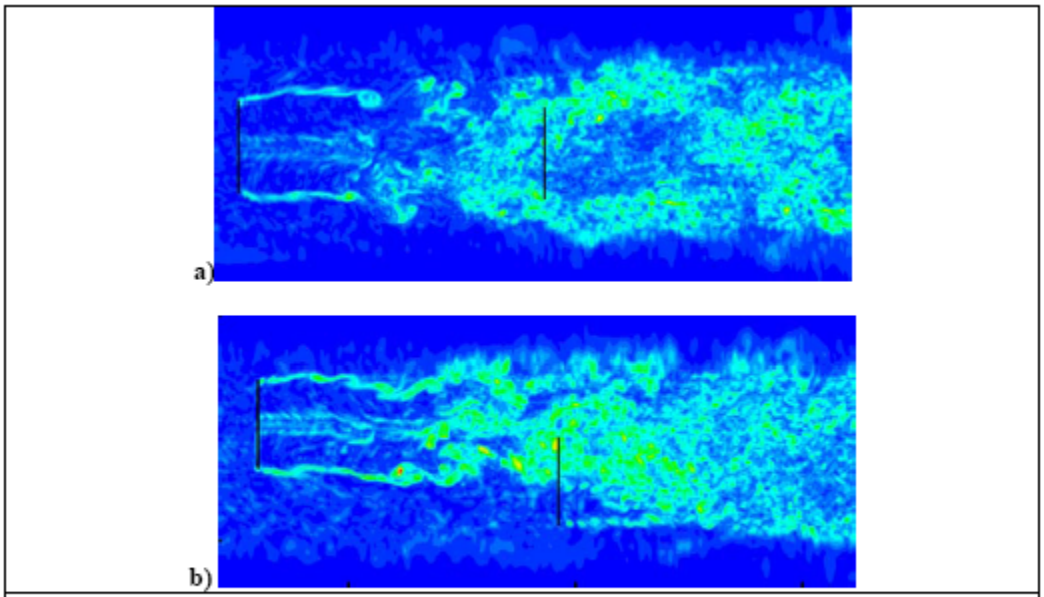
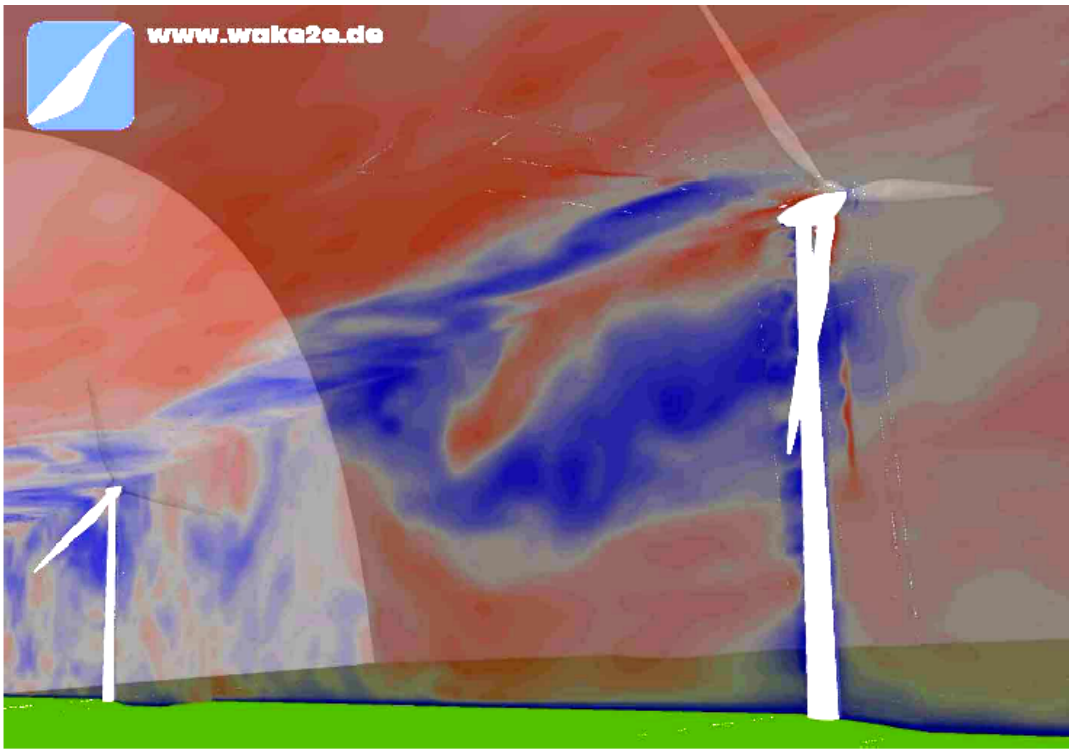


Figure 1: Instantaneous vorticity contours of flow field in a horizontal plane located at hub height. The mean wind is coming from the left and the wind turbines are indicated as black lines. Regions of high vorticity appear as light colors. a) Full wake; b) Half wake.

p.79 turbulent and meandering wake



OTHER INVESTIGATIONS

Wind turbine vortex structure 2008

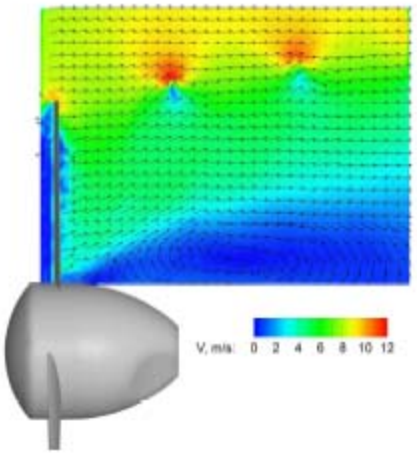


Fig. 4. Contours and vectors of average velocity in window h1.

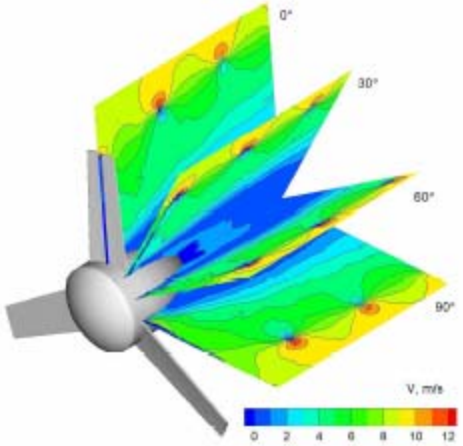


Fig. 5. 3-D average velocity field for azimuth planes h1 of 0°, 30°, 60° and 90°.

Wind turbines wake and turbulence

Figure 1. Smoke trail passed over blade-tips showing vortices [Ref 1]

The blade-tip vortices follow the blade rotation, so vortex cells have rotational components travelling at the tip speed, e.g. 160 Knots in the case of the smaller turbine at maximum tip speed. Further the blade-tip vortices start to mix with the downstream air-flow, and additional rotational components can be observed to form parallel with that downstream air flow.

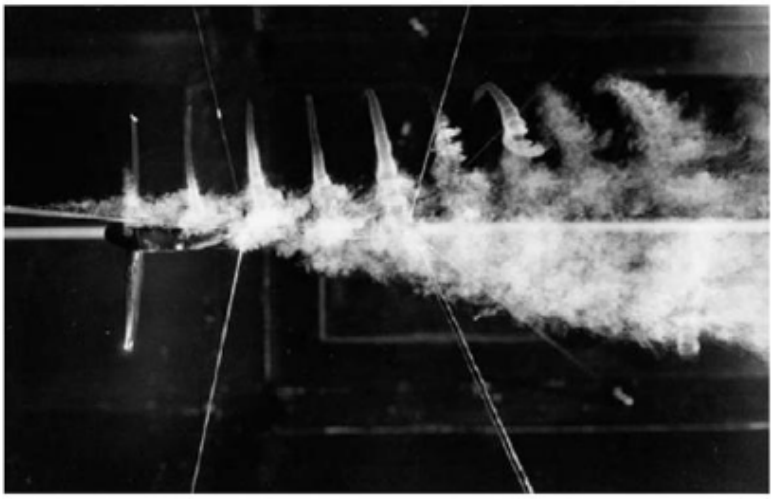


Figure 2. Smoke trail injected through centre of turbine showing expansion [Ref 1]

Studies show that the near-field wake turbulence behind a horizontal axis turbine extends downstream to 3 to 7 blade diameters. The exact extent depends on the blade torque coefficient and the tip speed ratio. Traditionally the near-field wake is considered to be 3 blade-diameters, but Figure 2 shows that it extends further..

The airstream is turbulent until at least this distance, and it is no coincidence that turbine separation in wind-farms clusters is 6 to 7 diameters in the direction of the prevailing wind direction and 3 diameters perpendicular to the prevailing conditions.

Figure 3 down-stream containment of the wake with low thrust [ref 2]

From NASA Ames wind-tunnel tests , where the turbine was operating at low thrust, you can see that the wake field is contained behind the turbine for up to 8 or 9 blade rotations, showing the extent of the near field propagation.

Horns Rev 1 Offshore Wind Farm

'Aeolus' turbulence behind the Horns Rev1 wind farm under very humid conditions, 12 February 2008 at 1300hrs. Photographer Christian Steiness